Juvenile American Shad Assessment in the Connecticut River – Fall 2017

Annual Report (April 2018)

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Introduction

American Shad (*Alosa sapidissima*) are anadromous fish that serve important ecological roles as forage for freshwater and marine fish, birds, and terrestrial mammals, and can support both recreational and commercial fisheries (ASMFC 2009, McDermott et al. 2015). They are the largest species in the clupeid family (herrings) and make annual spring migrations up rivers to spawn. Main stem dam construction disrupted annual spawning migrations beginning in the early 1800s resulting in population declines (Gephard and McMenemy 2004, Limburg and Waldman 2009, Mattocks et al. 2017). More recently, American Shad populations in New England have declined over the past several decades and were considered to be at an all-time low in 2007 by the American Shad Stock Assessment Subcommittee (SASC) due to excessive total mortality, habitat loss and degradation, and habitat access impediments (ASMFC 2007, ASMFC 2010, CRASC 2017). Further, they have been identified as a "species of greatest conservation need" by Massachusetts and other New England state agencies (MDFW 2015).

The Connecticut River Atlantic Salmon Commission (CRASC) coordinates restoration and management activities for American Shad and has a minimum annual run target to the river mouth of 1.7 million fish, with subsequent minimum escapement targets at main stem dams including targeted tributaries based on available habitat (CRASC 2017). Annual adult shad counts at Holyoke Dam have been relatively high since 2012 but remain lower than restoration minimum targets, particularly upstream of the Turners Falls Dam in Massachusetts and the Vernon Dam in Vermont/New Hampshire. While fish passage systems have improved to varying degrees in recent decades, it is unclear how main stem dams may affect the reproductive potential of the population (both spatially and temporally) as measured by juvenile production.

Movement patterns and life history traits are important considerations for managing and restoring anadromous species. American Shad are batch spawners, with historical rates of iteroparity in the Connecticut River estimated to average approximately 38% from the 1960s to early 1970s (Leggett 1976, Leggett et al. 2004), while more recent rates are estimated to range from 3-10% (CRASC 2017). Causes for this decline have not been definitively determined but are believed to include elevated mortality from ineffective downstream passage measures at hydropower facilities as well as passage delays at barriers on up and downstream migration (direct and indirect mortality) (Castro-Santos and Letcher 2010; CRASC 2017). Adult American Shad migrations from marine waters to the Connecticut River peak in May, with spawning occurring primarily from mid-May through late June (Leggett et al. 2004). Subsequently, juveniles typically develop in late June and July, and spend several months feeding before emigrating to marine waters in late fall (Crecco et al. 1983; O'Donnell and Letcher 2008). Juvenile shad length increases throughout the summer season until late fall, after which growth is insignificant (O'Donnell and Letcher 2008). Primary triggers for emigration are believed to be associated with declining autumn temperatures, with size having some effect although not a limiting factor (O'Leary and Kynard 1986, Limburg 1996). Juvenile American Shad peak

migration movements have been shown to occur in late afternoon and early evening (O'Leary and Kynard 1986), that primarily follow the river channel during out migration (Kynard et al. 2003). The timing of downstream movement has implications for survival, as the ability to transition to salt water becomes impaired at low (<10° C) water temperatures (Zydlewski et al. 2003).

The American Shad's complex life history coupled with multiple hydropower dams and a large pumped storage hydropower facility on the main stem Connecticut River has potential negative consequences to migrating adults (up and down running), return spawner reproductive potential, juvenile production (spatial coverage and density), and juvenile outmigration success. Juvenile shad mortality from larger main stem hydropower turbines may range widely depending on turbine design and operations and include other project sources of mortality such as spill at dam/gate structures (Franke et al. 1997). In the case of the Northfield Mountain Pumped Storage facility, with a pumping capacity of 15,000 CFS to its storage reservoir, there is no expectation of any survival for entrained eggs, larvae or juvenile shad (LMS 1993). Thus, understanding spatial ecology and quantifying natural and anthropogenic sources of mortality is essential to managing sustainable populations.

The ASMFC Amendment 3 for American Shad Management (2010) plan included, among other plan objectives: Maximize the number of juvenile recruits emigrating from freshwater stock complexes. As part of this plan's listed strategies, juvenile shad productivity and population structure data are an important component needed for development of sustainable fishery management plan. The ASMFC plan further identified potential threats including but not limited to: barriers to migration (need for safe, timely, effective migration), water withdrawals- "especially at pumped storage facilities" with concerns for associated delays in fish movement past the facility, and impingement or entrainment at intakes causing mortality or injury. The Connecticut River American Shad Management Plan (CRASC 2017) similarly prioritizes the need to establish safe, effective and timely downstream fish passage measures for juvenile shad that maximizes through/pass project survival. The CRASC plan also notes the important ecological contributions juvenile shad have while in freshwater.

Currently, the only juvenile American Shad monitoring effort on the Connecticut River is conducted by the Connecticut Department of Energy and Environmental Protection (CTDEEP) through the use of fixed beach seine stations (CTDEEP 2017). The Juvenile Abundance Index (JAI) dates back to 1974 and serves as a long term indicator of overall shad abundance, however, it is limited by spatial (downstream of Holyoke Dam) and statistical (fixed stations) components. Because this survey is conducted below the Holyoke Dam, the localized effects of upstream dams on juvenile American Shad productivity and emigration are unclear, and specifically, how dams affect habitat use and production in inter-dam segments.

Currently on the main stem river, the Turners Falls Dam Project, Northfield Mountain Pumped Storage Project (NMPS), Vernon Dam Project and Bellows Falls Dam Project are all in the Federal Energy Regulatory Commission (FERC) relicensing process and are located within the historic range of American Shad. Several recent FERC-required relicensing study reports have provided data on direct short-term (24 hour) mortality impacts on juvenile shad from balloon tag studies with indirect impacts less clearly defined due to challenges in maintaining control groups and the use of smallest available radio tags.

Goals-
This collaborative study aims to better understand juvenile American Shad productivity in the Connecticut River from Holyoke Dam (rkm 139) to Bellows Falls Dam (rkm 228), particularly through several metrics of young-of-year (YOY) abundance, size, and condition across various dammed sections. In addition, we aim to provide supportive evidence for ongoing juvenile abundance index surveys conducted by CTDEEP and CRASC. These efforts will provide baseline data for juvenile shad production, habitat use, and condition, and will ultimately inform local and regional management agencies and restoration efforts.

Objectives-
(1) Compare shad abundance metrics among three inter-dam segments and coinciding (nested) habitat sections across time and space.
(2) Calculate juvenile shad length-weight relationships as a proxy for condition and compare among inter-dam segments.
(3) Summarize sampling efficiency and variability and contrast shad abundance metrics with current monitoring efforts (CTDEEP) to ground-truth survey data and inform future monitoring priorities (random vs. fixed sites for predicting adult returns).

Methods
Study sites -
Holyoke, Turners Falls, Vernon, and Bellows Falls are consecutive, main stem dams located on the Connecticut River from Massachusetts into New Hampshire and Vermont (Figure 1). The Holyoke to Turners Falls, Turners Falls to Vernon, and Vernon to Bellows Falls dam sections are 57.3, 31.7, and 50.2 km in length, respectively. The Northfield Mountain Pumped Storage hydropower facility is located between the Turners Falls Dam and the Vernon Dam (Figure 1).
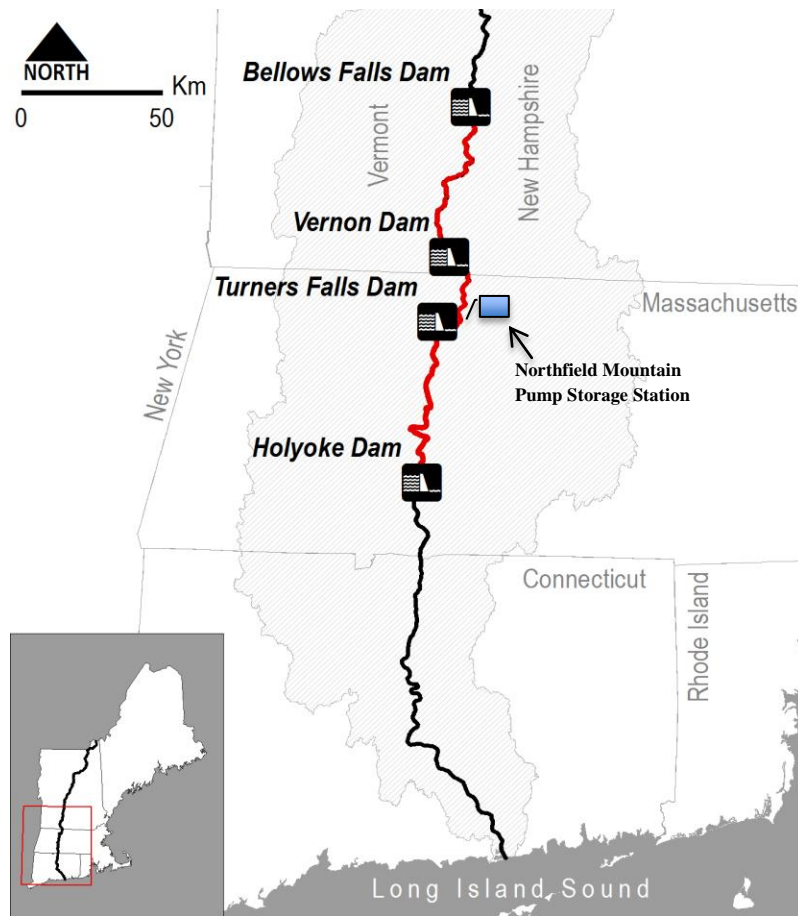
Figure 1: Connecticut River and main stem dam locations and the NMPS power station.

The amount of accessible shad habitat in relation to adult shad return/production potential in the Connecticut River has previously been described; table A (below) from Appendix 1 of the CRASC (2017) shows American Shad available rearing habitat by river segment in the Connecticut River (Table 1).

Table 1. American Shad habitat units in hectares (ha) with minimum adult annual production targets for main stem river segments (CRASC 2017).

Reach	m²	Ha	Adjustment	Ha	% of total	Adult Shad Return/Production (203 and 111 settings by habitat)	Project	Minimum target number
Main stem - mouth to Holyoke	56,766,060	5,677	0.85	4,825	54.8	979,498		
tributaries (5)		424		424	4.8	47,064		
Main stem - Holyoke to Turners Falls	13,688,717	1,369		1,369	15.5	277,881	Holyoke Fish Lift - passage	
tributaries (2)		109		109	1.2	12,099		687,088
Main stem - Turners to Vernon	7,620,241	762		762	8.7	154,691		
tributaries* (1)		139		139	1.6	15,429	Turners Falls Project - passage	397,108
Main stem - Vernon to Bellows Falls	10,421,641	1,042		1,042	11.8	211,559	Vernon Ladder - passage	
tributary (1)		139		139	1.6	15,429	passage	226,988
Totals		9,661		8,809	100.00	1,713,651		

Each dammed section was delineated by habitat section (impoundment and riverine); impoundment sections were classified by lower, middle, or upper impoundments, depending on the length and habitat conditions of each segment. The Holyoke section was the only inter-dam segment where the riverine habitat section (north of Rte. 116 Bridge) was sampled due to access difficulty in other segments. Both the Holyoke impoundment and Vernon impoundment sections were assigned three sample zones (lower, middle, and upper) due to their length and logistic considerations/sampling time constraints, while the shorter length of the Turners Falls impoundment only required two zones.

Fish sampling -
Electrofishing surveys were conducted from 8/22/17-10/18/17, with sampling beginning 20 minutes after sunset and continuing until 5 sampling runs were completed, typically concluding by 10:00 pm. Two electrofishing boats using pulsed DC current and standardized waveform (Smith Root, Midwest Lakes) were used with two netters located at the bow. Juvenile shad were netted, identified by date and run # for next day processing, and immediately placed on ice and either frozen for later processing or processed the following day. At the end of sampling, frozen shad were thawed and total length (mm) and weight (g) were recorded.

Dammed sections were surveyed sequentially, with one section being sampled per sampling night and typically two sampling nights per week, in an on-week/off-week regiment. We used a random number generator in Microsoft Excel to select sampling locations delineated by 0.5 river kilometer (rkm) cells. Sample cell sizes (0.5 km) in these impoundment zones ranged from 30 (Vernon section) to 25 (Holyoke section). Electrofishing runs started at the most upstream selected site, and followed a zig-zag pattern across the river from shoreline to shoreline in a

downstream direction. GPS tracks were recorded and stored using WGS 1983 Geographic Coordinate System. An example of the sampling run tracks completed over the course of the study is shown in Appendix A (Figure A.1). Paired electrofishing runs with MADFW and USFWS boats and crews were conducted to test sampling effort and efficiency and were conducted over multiple sampling days.

Results

Paired electrofishing runs (n=16) showed that effort and catch were comparable between the two sampling boats; mean fish/minute was 0.51 and 0.61 (SD=0.59, 0.5), and no significant differences were detected (student's T test, p=0.05).

A total of 148 runs were conducted between the three dammed sections of river, with a total of 1,006 juvenile shad collected (Table 2). Sampling of reported data was initiated on August 22, 2017 and concluded on October 18, 2017. Sample effort, in terms of total sample runs, over the study period, was highest in the Holyoke section (n=78) followed by Turners Falls section (n=39) and Vernon section (n=31). The USFWS sampled the two upstream sections and in this pilot study year, alternated sampling between weeks, reducing the overall sample effort for both.

Table 2. Summary of electrofishing runs for month, dam reach section, and habitat section.

Month	Dam Section	Habitat Section	# of Runs
August	Holyoke	Lower Holyoke Impoundment	10
August	Turners	Lower Turners Impoundment	5
August	Turners	Upper Turners Impoundment	12
September	Holyoke	Holyoke Riverine	4
September	Holyoke	Lower Holyoke Impoundment	6
September	Holyoke	Middle Holyoke Impoundment	15
September	Holyoke	Upper Holyoke Impoundment	7
September	Turners	Lower Turners Impoundment	6
September	Turners	Upper Turners Impoundment	6
September	Vernon	Lower Vernon Impoundment	6
September	Vernon	Upper Vernon Impoundment	5
October	Holyoke	Holyoke Riverine	5
October	Holyoke	Lower Holyoke Impoundment	11
October	Holyoke	Middle Holyoke Impoundment	10
October	Holyoke	Upper Holyoke Impoundment	10
October	Turners	Lower Turners Impoundment	5
October	Turners	Upper Turners Impoundment	5
October	Vernon	Lower Vernon Impoundment	10
October	Vernon	Upper Vernon Impoundment	10

We calculated Catch Per Unit Effort (CPUE) as the number of shad collected per minute. Mean CPUE (fish/minute) for the Holyoke, Turner Falls, and Vernon Sections were 0.54, 0.14, and 1.4, respectively (Figure 2).
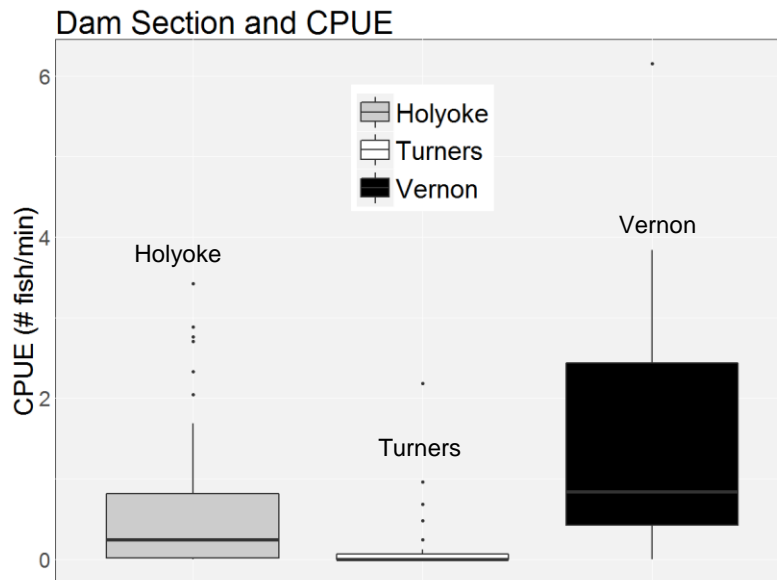

Figure 2. YOY Shad CPUE by dam section. Boxes represent 25th to 75th percentile, median (center line), and outliers (points).

We grouped impoundment sections across all three dam sections to compare CPUE across lower, middle, and upper impoundments, as well as riverine sections (Holyoke; Figure 3). CPUE across habitat sections were comparable with no visually observable differences in means, although variability was highest in lower impoundment zones.
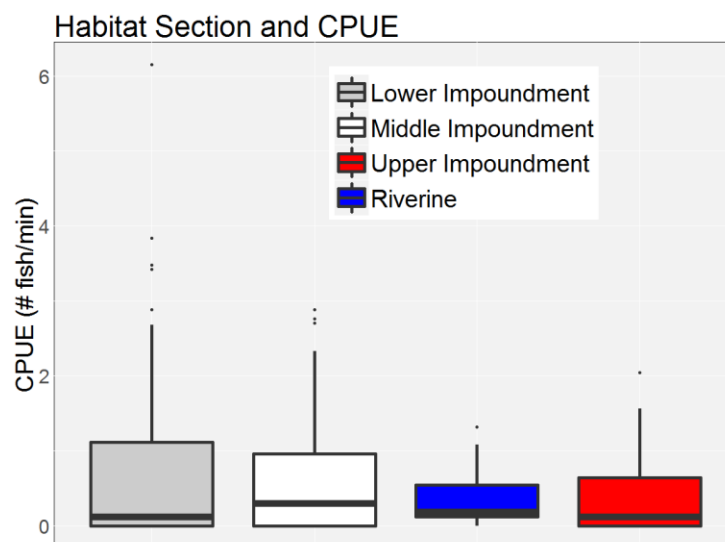
Figure 3. YOY Shad CPUE by impoundment section in the Holyoke dam section.

Mean Young-of-the-Year (YOY) shad total lengths for the Holyoke, Turner Falls, and Vernon Sections were 88.2, 84.5, and 83 mm, respectively. A pattern of larger fish downstream was observed, as expected (Figure 4).
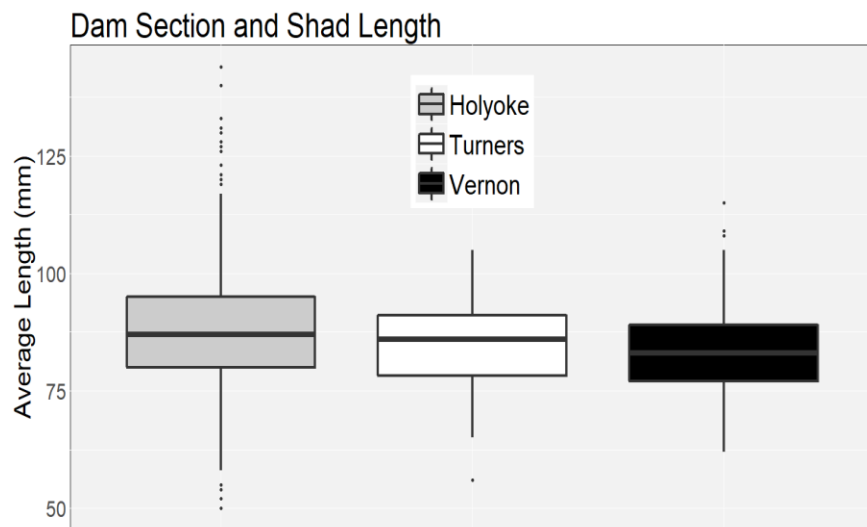

Figure 4. Average YOY shad total length by dam section.

Total shad length increased steadily from August through October, as expected with seasonal growth (Figure 5).
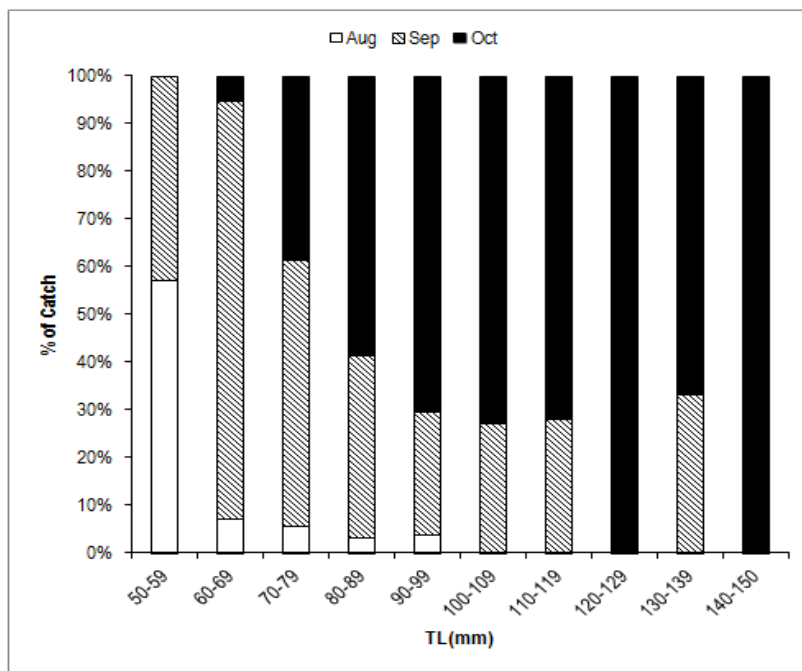

Figure 5. Shad length by % of catch from August to October.

Length and weights were logged and plotted with regression lines as an indicator of condition. Logged length and weight regressions had subtle differences between sections. At smaller sizes, shad of a given length had higher weight in the Holyoke and Turner Falls sections when compared to the Vernon section. However, larger shad had increased weights for a given length in the Vernon section (Figure 6). This pattern seems largely driven by low weights at small sized in the Vernon section.
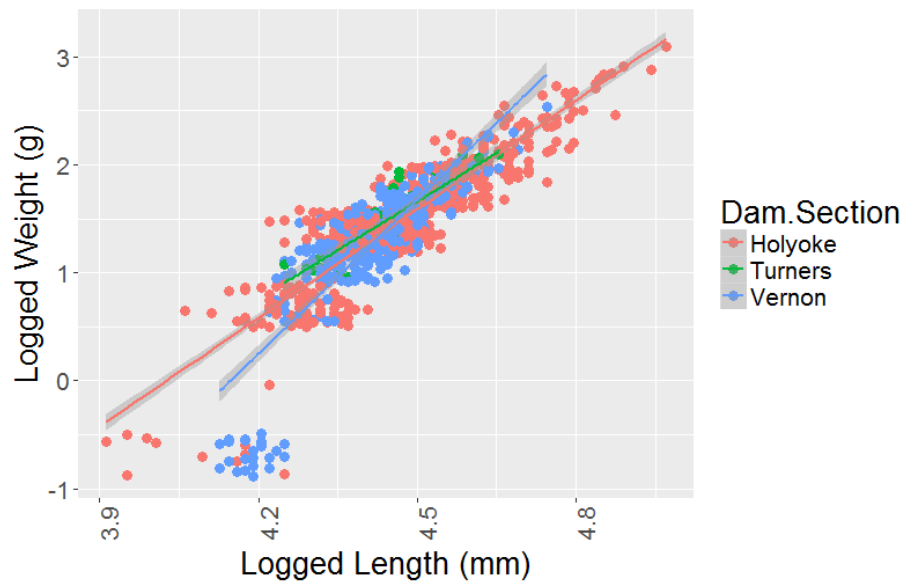

Figure 6. Regression lines for logged length and weight of YOY shad, by dam section.

In addition to fish metrics, environmental data was collected to provide baseline data for factors triggering life history events. Discharge data collected in Montague (USGS) and water temperature data collected from the Vernon tailrace (USFWS) show flow and temperature during the fish sampling period (Figure 7).
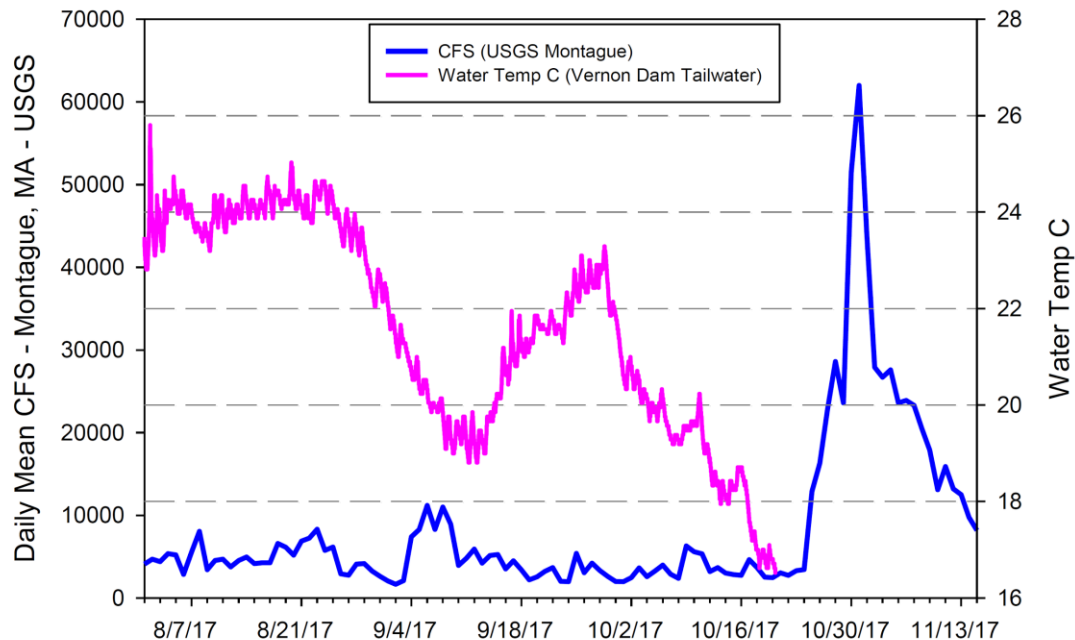
Figure 7. Discharge and temperature data in Montague and Vernon tailwater, respectively.

Discussion

Overall, YOY American Shad CPUE was variable, with the Vernon section having the highest values, followed by Holyoke, then Turner Falls. Shad lengths were greatest in the Holyoke section, following a northerly pattern of decreasing length with the Turner Falls and Vernon section shad comprised of smaller individuals. This size pattern is expected considering the seasonal movements of shad downstream with cooling water temperatures. Further, the delay in adult migration upstream coupled with batch spawning behavior of adults indicates variable spawning times across dam sections. In 2017, American Shad upstream fishway counts included 536,670 passed by the Holyoke Fish Lift, followed by 48,727 passed at the Turners Falls Gatehouse Ladder and 28,682 passed at the Vernon Ladder. The CRASC Plan (2017) adult American Shad minimum passage count targets for each dam passage facility were not achieved in 2017 to varying degrees for known reasons; Holyoke (78%), Turners Falls (12%), and Vernon (13%). Each facility is impacted by the preceding fish passage facilities effectiveness (e.g., Turners Falls passage is a limiting factor for Vernon passage count) with Turners Falls known to have upstream fish passage issues in contrast to Holyoke. The date when 50% of the 2017 adult run counts were observed at Holyoke, Turner's, and Vernon were approximately 5/21, 5/27, and 6/3, respectively, indicating upstream delays in spawn timing. This timing likely results in variation in YOY length and outmigration timing by juveniles, although this was not directly tested. A fecundity and spawning study recently completed by McBride et al. (2016) on Connecticut River American Shad determined that females, on average, spawned at a mean interval of 4.8 days (fish upstream of Holyoke Dam) with a mean of 6.7 spawning batches, and a

mean of 45,950 eggs, during the spring of 2015. Based on this research, we hypothesize that over the course of the spawning run, a high proportion of fish will continue to move upstream until their gametes are depleted (spent) or environmental conditions become too challenging (later season water temperatures), leading to a downstream migration. It was beyond the scope of this study to understand the extent of spawning activity or spawning success that may influence the extent of juvenile production observed in the later summer.

It is clear that a disproportionate number of adult shad remained within the Holyoke to Turners Falls Dam segment (487,943) versus the number of shad that entered the Turners Falls Dam impoundment (48,727), which is an order of magnitude difference. However, for the adult shad that passed into the Turners Falls Dam segment approximately 59% eventually passed upstream of the Vernon Dam (28,682). Given this rate of upstream passage at Vernon Fish Ladder, a total of 20,045 shad remained in the Turners Falls Dam impoundment. It is unclear what the spawning contributions are of shad passing from one segment to another without biological monitoring at fishways for sex ratio and spawning condition assessments. Shad spawning success is believed to be further influenced by environmental and operational conditions (e.g., rapid water level fluctuations from hydropower peaking operations).

Observed differences in regression lines for logged lengths and logged weights may be indicative of forage availability (plankton). Higher condition of smaller shad in lower sections (Holyoke and Turners) may be due to warmer temperatures which may increase primary productivity and plankton abundance. Higher condition of larger shad observed in the Turners section could be due to a variety of interacting factors including decreased density of shad in later summer from lower adult reproductive potential, differing habitat conditions, mortality, and/or outmigration. Downstream migration has begun at this stage (October); this may reduce competition and increase growth of shad that remain in the system. Additional data collection including downstream passage monitoring, fine-scale environmental variables, and a better understanding of life history events could better inform observed differences in CPUE, length, and condition (O'Donnell and Letcher 2008).

It is unclear the extent to which juvenile shad CPUE values may be a reflection of mortality due to hydropower passage effects as they shift to downstream habitats. We can only know that the juveniles sampled upstream of Vernon Dam would not have any exposure to that force of mortality (turbine route rates) until outmigrating past the Vernon Dam. Estimates of juvenile shad mortality from dam facilities (turbine, spill other routes) exist as do estimates for the NMPS although there are complications with estimates in many cases (such as > 48 hour survival in balloon tag studies or challenges with radio tagging juveniles). The extent of American Shad eggs, yolk sac larvae, post yolk sac larvae and juvenile entrainment (losses) as a consequence of the operation of the Northfield Mountain Pumped Storage facility has been reported for a 1992 study season (LMS 1993), and more recently for a 2016 study season (Kleinschmidt 2016). The

2016 NMPS entrainment study reported entrainment for: American Shad eggs (9.5 million) and larvae (5.4 million), with no distinction made on larval stage, which has implications for stage specific survival rate application. In addition, juvenile shad entrainment was not provided due to un-reliable estimates from issues with radio tagging methods. Importantly, the 2016 study results and expansion estimates for losses did not utilize the Crecco et al. (1983) daily survival rate for the juvenile life stage of shad – a high daily rate (0.98) to be applied for a period of 70 days (refer to Kleinschmidt report table 3.4-1). This was in spite of that study's use of Crecco rates for the four preceding larval life stages, with no explanation, for omitting the last "in-river" survival rate for juveniles. This omission of a daily survival rate for juveniles, reported as (S) 0.98, that should be applied for a period of 70 days [i.e. $S = (0.98)^{70} = 0.24$] leads to a significant underestimation of the magnitude of lost juveniles – specifically for in-river period up to the time of outmigration. The company report uses the Crecco larval stage survival rates (L1, L2, L3, L4 - sizes under 25mm) but then applies a very broad temporal and spatial scale Environmental Protection Agency– lumping juvenile in-river stage, juvenile outmigration, and at-sea survival - (S) of 0.000611 (EPA 2004). The selective omission is not explained in the analyses although the U.S. Fish and Wildlife Service May 2017 letter to FERC on this study report pointed out this issue. Applying the Crecco "juvenile" survival rate, to the data reported in Kleinschmidt (2017; field study in 2016), yields an estimated loss of juveniles from larval entrained shad of 1,029,865 fish, rather than the reported 2,200 fish (up to age-1 in ocean) in 2016, and does not include an estimated additional 44,842 lost juveniles based only on egg entrainment (using Crecco river-specific, life stage survival estimates to end of juvenile stage). As the specific larval stage of entrained larvae was not identified in the Kleinschmidt report, the most conservative assignment (all larval stage 1) was used, which would under-represent the expected but unknown number of advanced stages that were entrained over the study season, resulting in this extrapolated loss actually being greater in magnitude.

The 1992 NMPS entrainment study reported entrainment for; American Shad eggs (1.1 million), yolk sac larvae (2.7 million), and post yolk sac larvae (10.5 million). That report did not include the application of river specific (stage specific) survival rates to determine the subsequent loss in juvenile shad from these early life stage entrainments. However, this study did estimate a total of 37,260 juvenile shad entrained (lost) based on net sampling at the NMPS. The application of the Crecco et al. (1983) river-specific daily survival rate for "post yolk sac" fish (>25 mm) entrained in 1992, if assumed to be >25 mm, estimates a loss of over 2.5 million juvenile shad up to the time of outmigration (70 day juvenile life stage) for that entrainment group alone.

Juvenile American Shad survival rates have been studied at Vernon Station which has both Francis and Kaplan design turbines of different sizes. Immediate survival through a Francis turbine (unit #10) for juvenile shad was estimated at 94.7% in 1995 (Franke et al. 1997). A partial depth downstream guidance louver was also installed in the 1990s to aid in directing salmon smolts to the entrance of a downstream fish passage pipe. As part of the current

relicensing process, studies on both downstream movement to the project, passage routes, timing and turbine survival have been completed in the fall of 2015. Juvenile shad were shown to experience generally minimal delay but did use turbines as a primary passage route (vs. downstream bypass options <10%). Juvenile shad survival through two turbine types, Francis Turbine (#4) and a Kaplan Turbine (#8) was examined; a one hour direct survival estimate for the Francis Unit was 91.7% and 95.2% for the Kaplan, with injury rates <5%, and longer term survival (48hr) could not be determined.

At the Turners Falls Dam, juvenile shad route selection, delay, and mortality were assessed in several project areas: 1) spill at the dam (bascule gate #1 and #4), 2) Station 1 (small power station located off the main power canal) and 3) Cabot Station, terminus of the power canal. Juvenile shad survival rates varied at bascule gates depending on gate and level of spill, ranging from 47.7% - 75.6% at bascule gate #1 to 59% - 75.6% at bascule gate #4. Radio tagged juvenile shad route selection followed flow with most study fish using the power canal, unless spill was present (varied for treatments). Juvenile shad survival through smaller Francis Turbine at Station 1 (located off the main power canal) was determined to be 67.8% and 76.6%. Radio tagged juvenile shad predominately stayed in the main power canal, making their way to the Cabot Station. Juvenile shad survival through the Cabot Station Francis Turbine (all five the same) was estimated as 95% (24 hr). As in the case of all reported turbine study estimates discussed here, longer term survival (48 hr) could not be determined.

The Holyoke Dam, Hadley Falls Station, has had several significant downstream passage measures implemented since the 1990s. Fish that may enter the power canal at the gatehouse are directed by a sharp angle, full width, full depth guidance louver system, to a downstream fishway entrance at its downstream terminus, where fish are taken via a fish pipe for release directly into the tailrace. At the turbine intakes, a full depth reduce rack spacing screen (2 inch) was installed in 2015. Two submerged downstream fishway entrance bypasses are located in that rack, that discharge into the spillway plunge pool (constructed for fish passage). In addition, the bascule gate adjacent to the turbine intakes includes increased fish passage flow discharge and an "NU-Alden Weir" insert, designed to enhance passage. Flow is directed to a flip bucket at the dam apron, whereby water velocity is reduced as it enters the downstream plunge pool and overshoots the spillway upstream passage entrance. The determination of mortality rates for juvenile shad that pass via the "new" submerged bypasses or the spill gate, both of which utilize the "new" flip bucket (overshoot) to the plunge pool have left some debate on the fates of some of the radio tagged juveniles. The company study report following meetings was updated to provide a range of potential survival results. The 24 hour survival rate was estimated as 87.5%. While an overall route of passage, proportion of where juvenile shad go was not part of the new structures evaluation. Immediate (1-hr) turbine passage mortality rates for juvenile shad at Holyoke were determined in 1994 by a balloon tagging study; rates ranged from 0.0% ± 14.5% (95%

confidence interval) at partial turbine capacity to 2.7% ± 16.2% at full capacity (Mathur et al. 1994).

Management Implications
Estimating downstream mortality of juvenile shad remains an important challenge for future monitoring and restoration efforts. Observed differences in juvenile shad population metrics across and within dammed sections has management implications in achieving CRASC management plan goals and objectives, including restoring the ecological role of juvenile shad through the outmigration period. Ensuring safe, effective and timely downstream passage through/past hydropower facilities is an important objective for sustaining populations of migratory fish. Hydroacoustics, high resolution sonar cameras (DIDSON), coupled with physical sampling methods for enumerating downstream passage could be used in the future to better monitor migration rates and timing, as well as to better understand growth and mortality of juveniles in freshwater habitat.

A better understanding of movement patterns and habitat occupancy of juvenile shad within dammed river sections would further our understanding of passage and habitat access needs. This is particularly important as major dams are currently under license review and negotiation. The continued collection of data by government agencies is integral to contrast data collected by private consultants through the hydropower licensing process, and further data collection across multiple years would benefit management efforts by capturing greater spatial and temporal variability.

This assessment provides supportive evidence to existing interagency shad monitoring efforts in the Connecticut River. Connecticut Department of Energy and Environmental Protection implements annual fixed beach seine surveys initiated in 1978, however this effort has never been duplicated with a random sample design and is limited to downstream of the Holyoke Dam (Figure 8). Fixed-station sampling is ideal for monitoring changes in specific locations over time; however, random sampling offers more robust estimates of population parameters by eliminating spatial sampling bias. When both methods are used simultaneously, they can offer "ground truthing" for more sound population indices for predicting numbers of returning adults. Construction of stock recruitment relationships when adults return in 3-5 years would be particularly useful when coupled with fixed station seining data from CTDEEP.
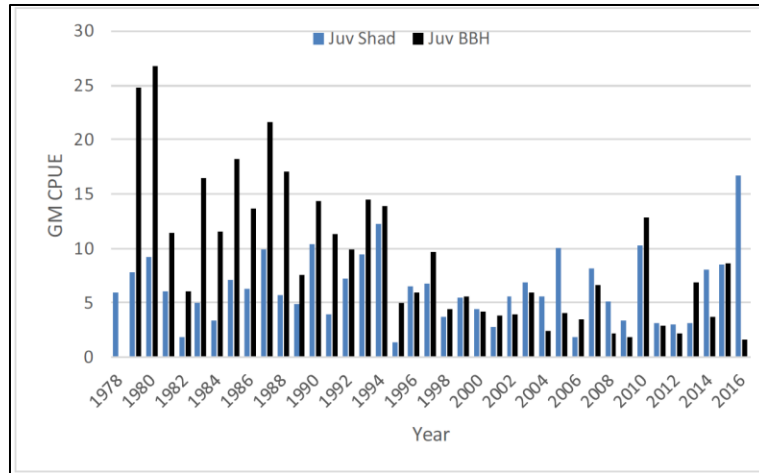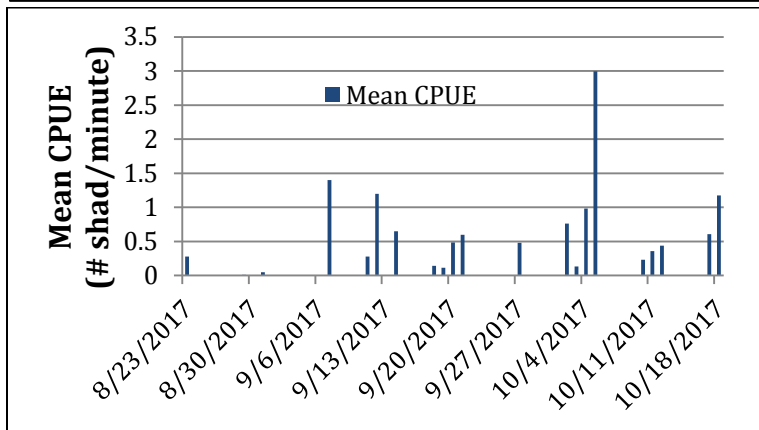
Figure 8. Long-term JAI seining data from CTDEEP (panel A) compared to short-term 2017 electrofishing data (panel B).

Juvenile productivity and population data is an important component of fisheries management, particularly for data-limited species with significant habitat fragmentation. Anthropogenic stressors such as dam infrastructure, pollution, and climate change will require flexibility and adaptive management along with continued evaluation of population and life history characteristics to maintain current and future levels of mortality from fishing. Continued monitoring and interagency collaboration will be integral to the successful management of migratory species that cross ecosystem and management boundaries, particularly those with complex life histories facing long term habitat access impediments.

Acknowledgements

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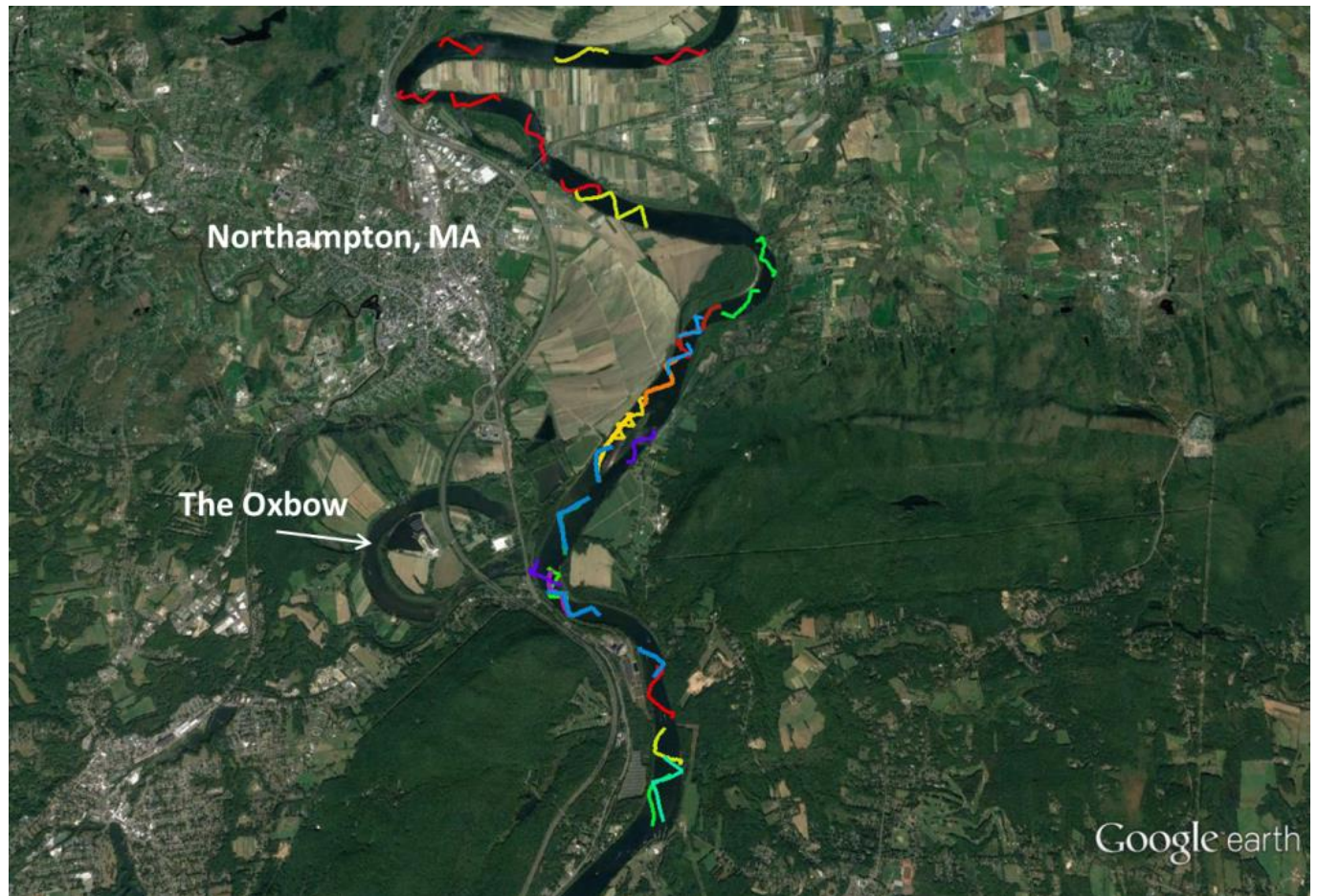
Figure A1. Electrofishing runs in the middle Holyoke impoundment section. Each line represents an individual run; colors are random to distinguish runs.
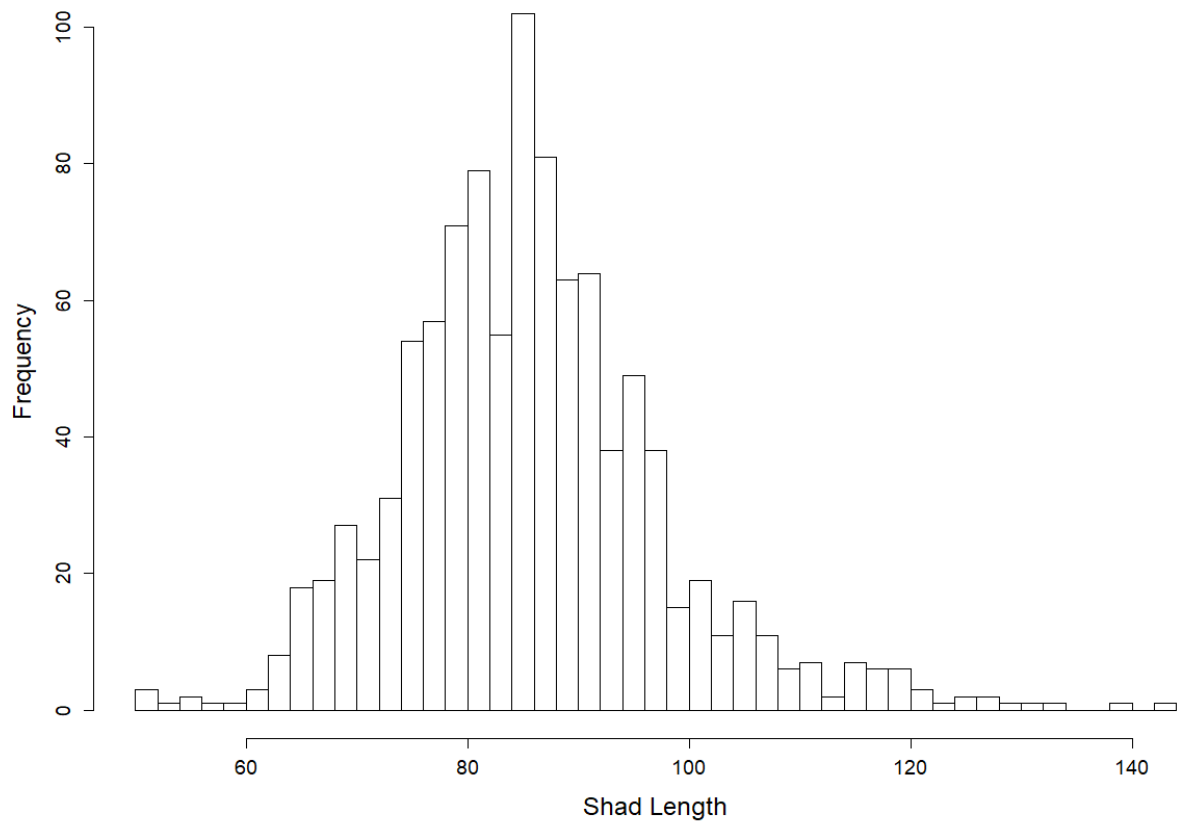
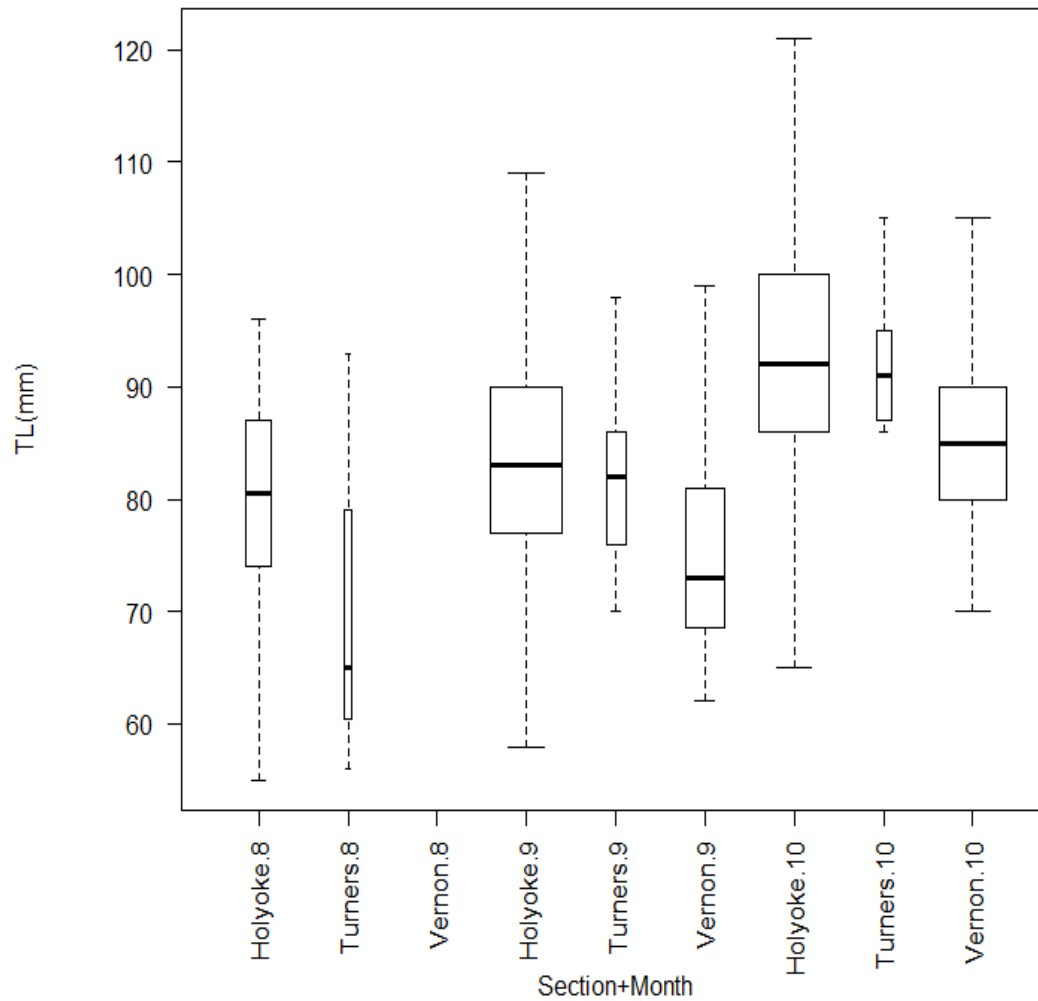Figure A2. Length frequency histogram of juvenile shad captured from electrofishing surveys.

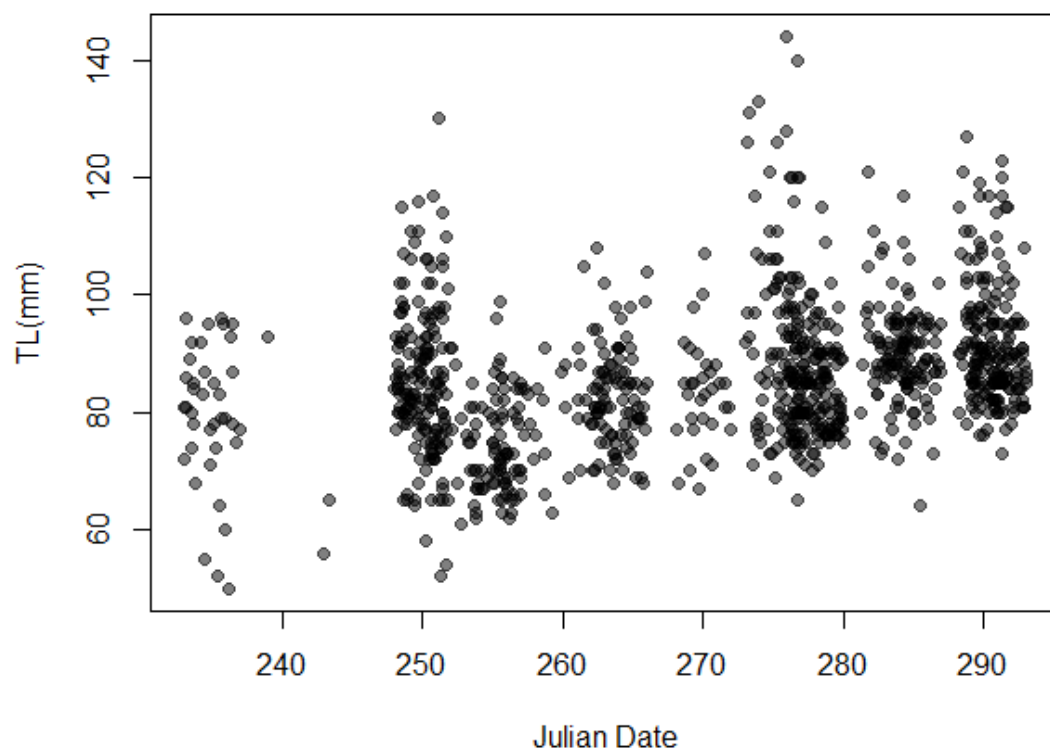Figure A3. Total length of shad by dam section and month, and box width conditioned on sample size.
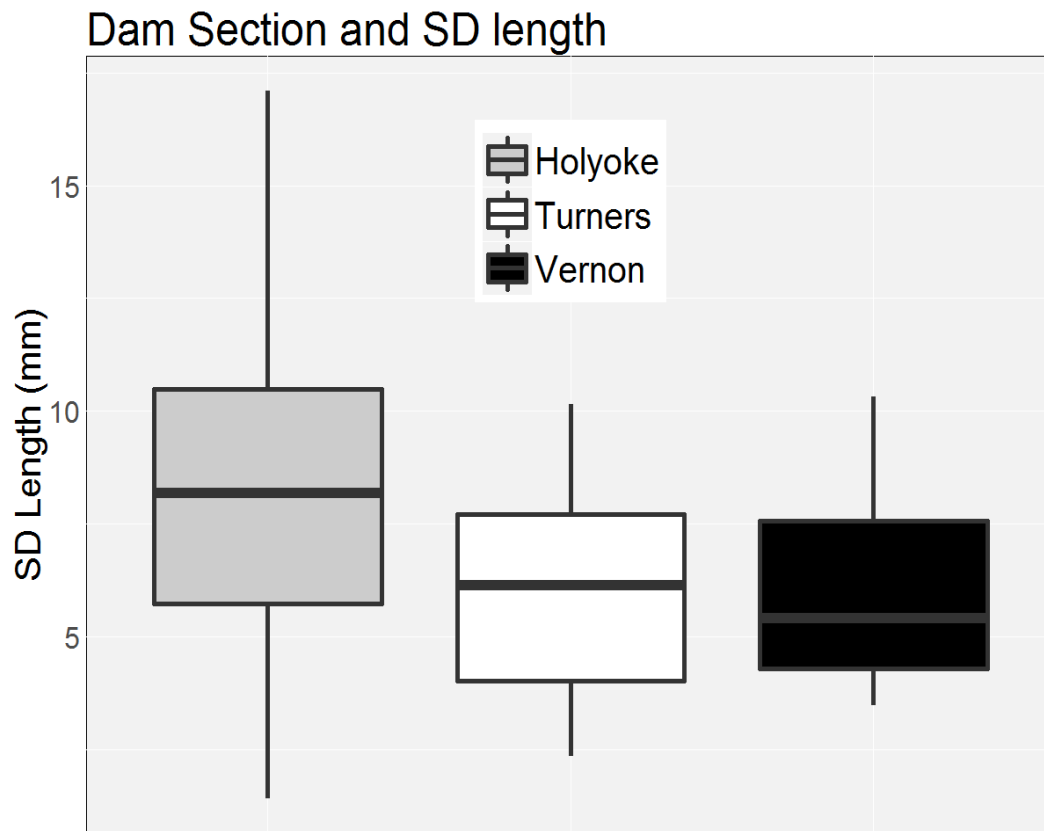
Figure A4. Shad total length by Julian date.

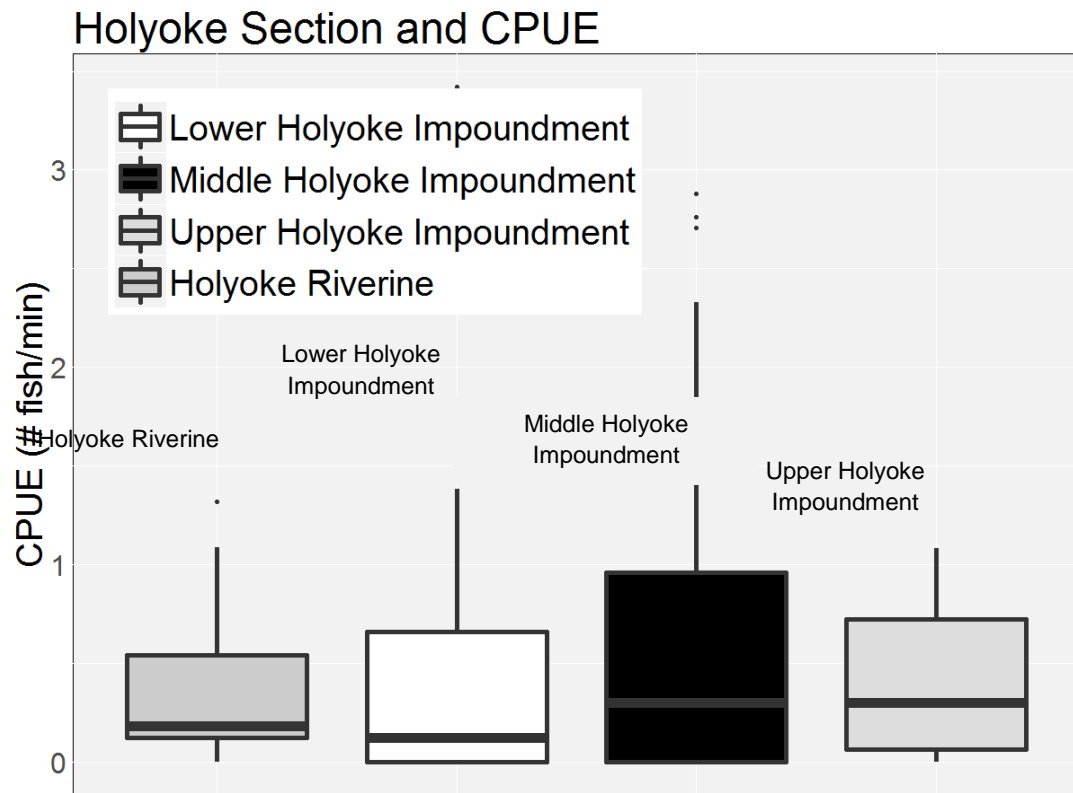Figure A5: Standard deviation of shad length by dam section.

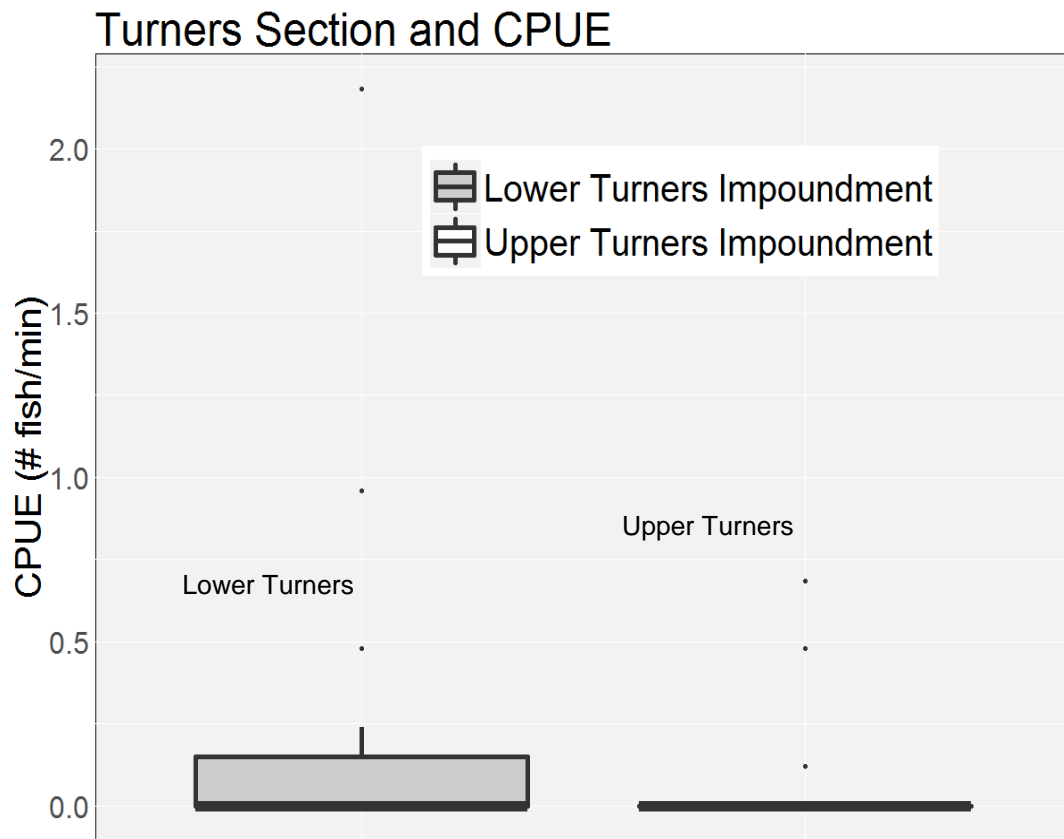Figure A6: CPUE by impoundment/habitat within the Holyoke dammed section.

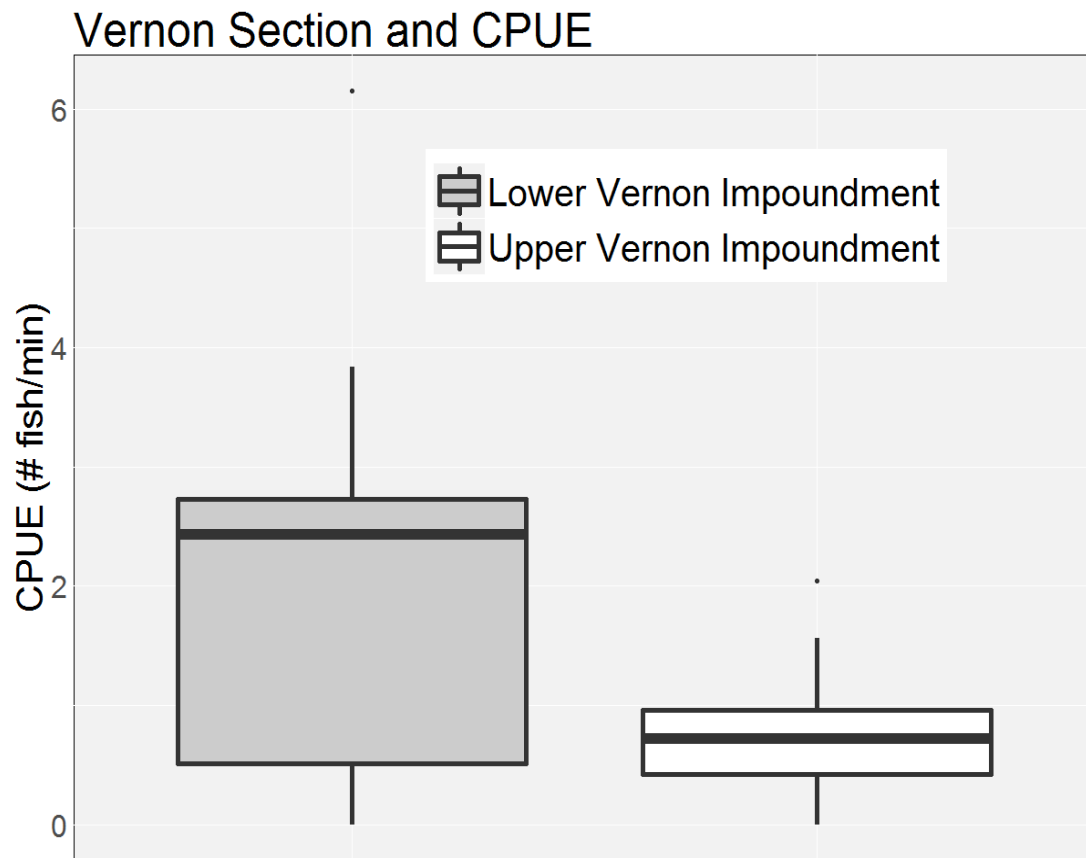Figure A7: CPUE by impoundment/habitat within the Turners dammed section.

Figure A8: CPUE by impoundment/habitat within the Vernon dammed section.